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Application of NASTRAN/COSMIC in the Analysis of Ship Structures to Underwater Explosion Shock

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SUMMARY

This paper presents the application of NASTRAN/COSMIC in predicting the transient motion of ship structures to underwater non-contact explosions. Examples illustrate the finite element models, mathematical formulations of loading functions and, where available, comparisons between analytical and experimental results. One example shows the use of NASTRAN/COSMIC coupled with a structure/water interaction theory to predict early time dynamic response of the USS YORKTOWN during shock trials in 1984. Another example is the analysis of a MK-45 gun conducted in support of the Ship Systems Engineering Standards (SSES) program. Use of the substructuring feature of NASTRAN/COSMIC in the analysis of the Vertical Launch Missile System is illustrated for the recently constructed USS MOBILE BAY. Another example illustrates the analyses of two mast structures on the USS KAUFMANN. Finally, an example of the analysis of a SWATH structure is presented.

INTRODUCTION

The evaluation of dynamic responses of surface ships and submarines to a shock environment is a very important problem in naval research. The fundamental characteristic of the shock experienced aboard naval vessels is the sudden increase in the velocity of the structural member. Equipment supported by these structural members may be adversely affected by this sudden increase in motion. There are two basic types of damage to equipment which concerns the naval designer: mechanical damage and mal-operation.

Surface ship shock loading may result from three sources: 1.underwater non-contact explosions, 2. contact explosions and 3. air blast from aerial bombs or from the vessel's own armament. Of particular importance to the United States Navy is the response of ship structure to underwater non-contact explosions. The Underwater Explosions Research Division (UERD) of the David Taylor Naval Research and Development Center (DTNSRDC) uses both analytical and experimental techniques in research efforts aimed at finding solutions to this complex problem. One of the primary analytical tools used at UERD is NASTRAN/COSMIC.

ANALYSIS OF USS YORKTOWN

The USS YORKTOWN (CG-48) is the second ship constructed in the

USS TICONDEROGA CLASS of guided-missile cruisers. The USS YORKTOWN has an approximate displacement of 9,100 tons. This ship is a revised version of the USS SPRUANCE class destroyer using the same hull and propulsion system but incorporating the AEGIS weapon system(1). The USS YORKTOWN was shocked tested in September of 1984. The purpose of this section is to illustrate the use of NASTRAN/COSMIC coupled with a structure/water interaction theory to predict the early time vertical response of the entire ship during these trials.

The simplest representation of the structure/water interaction is with an impulse equal to the momentum of the displaced water in the free field. This impulse is applied from below to a beam model of the ship. At the termination of the impulse load atmospheric and gravitational forces are applied to the model from above (Refer to Figure 1). This approach is reasonable because the ship displaces it's mass in the water and buoyant forces are lost due to cavitation around the ship during the impulse loading phase of the ship motion. This approach emphasizes the structural response while de-emphasing the complex fluid-structure interaction; thereby, considerably simplifying the analytical calculations of the dynamic response.

Previous UERD research efforts have shown that the total momentum of a structural node on a surface ship can be approximated by the use of the "spar buoy" model. The fundamental assumption of the "spar buoy" model is that a given structural node is "kicked off" with the same average velocity as a column of water with the same depth as the draft of the ship at the corresponding location in the free field. The derivations of the equation to compute the total momentum can be found in Reference 2.

A finite element model consisting of forty flexural beam elements was utilized to evaluate the dynamic response of the ship. The element's sectional properties (i.e., moment of inertia and cross sectional area) and mass distribution were obtained from design calculations performed by the Naval Sea Systems Command (NAVSEA). Previous analytical and experimental work (3) has demonstrated that the higher frequencies of vibration are significantly effected by the exclusion of shear deformation. Shock loadings tend to excite the higher modes of vibration; therefore, to ensure more accurate results the contribution due to shear energy via an effective shear area was included in the analysis. Due to the spherical nature of the shockwave, proper consideration was given the the arrival of the shockwave at each structural node. Gravity and atmospheric pressure were accounted for by use of a loading function applied at the time of cut-off of the impulse load. The analysis was performed on a CDC 176 mainframe.

Figure 2 illustrates a comparison of the normalized experimental and analytical results for a location on the ship's keel near the stern. This figure illustrates excellent correlation between the experimental and analytical curves with respect to shape and peak value for the first thirty milliseconds. A similar comparison is illustrated in Figure 3 for the velocity at the

amidships location. Finally, a comparison of the velocity at a location near the bow of the ship is depicted in Figure 4 . As in the case of the other two location, excellent correlation was obtained for the first thirty milliseconds.

ANALYSIS OF A MK 45 GUN MODEL

Modular weapons installation is a very important concept to naval ship and weapons designers. The modular weapons design concept offers the United States Navy several advantages over the classical methodology of designing ships. The first major advantage is the flexibility of upgrading weapons as the technology of weapon design changes in the future. Another important advantage is the ability to interchange weapons systems in the fleet. This allows the Navy to essentially change the mission of any given ship as may be required by the ever changing world situation.

DTNSRDC/UERD was tasked to participate in the analysis and development of design standards for modular weapons via the Ship Systems Engineering Standards (SSES) program. The first part of this task was to perform a detailed analysis of the MK 45-54 caliber 5 inch gun module. To accomplish this task a NASTRAN/COSMIC finite element model (see Figure 5) was prepared for the forward ship zone between structural bulkheads of the DDG-51 at the location of the gun module. A NASTRAN/MSC model (see Figure 6) of the gun module developed by FMC/NOD was converted to a NASTRAN/COSMIC model and then interfaced with the ship model. The combined model was accelerated at the hull with a prescribed motion history to simulate the expected motions of the ship during a full scale shock test in the vertical and athwartship directions.

The basic assumption in the computation of the transient motion of the MK 45 gun module is that the hull of any section of the ship between transverse bulkheads moves as a rigid body in the vertical and athwartship directions. To compute this rigid body motion in the vertical direction, the method outlined in the previous section was utilized. Specifically, a NASTRAN/COSMIC beam finite element representation of the entire ship was analyzed in the time domain. The ship loading was via the "spar buoy" assumption. The output from this analysis was then used as input for the analysis of the gun module.

The translational motion in the athwartship direction is an adaptation of a technique for computing submarine rigid body motion. Figure 7 illustrates the structural model used to compute the rigid body motion of the hull in the athwartship direction. This model assumes the hull is 1) a rigid body, 2) the loading function is an exponential decaying function calculated by the explosive charge similitude equation, 3) the loads are applied to the structural nodes on the shot side of the hull and 4) the resistance of the water on the side away from the shot is proportional to the velocity (i.e., viscous damping). Writing the equations of motion and numerically integrating through the time domain yields a prescribed displacement for the motion of the hull. Figure 8 illustrates a normalized comparison of the analytical and

experimental values for a typical cross section of the USS YORKTOWN. As illustrated, the early time history of the ship is predicted quite accurately.

The finite element model of the ship structure consisted of CQUAD1, CTRIA1 and CBAR elements. Orthotropic plate theory was assumed in modeling the plate and stiffener combination of the ship bulkheads. A coarse finite element mesh was assumed since interest was in the computation of displacements and not stresses in the ship structure. The computation of the response of structures due to impulsive loadings, the computations were performed on the coupled equations of motion through the time domain. To achieve the prescribed acceleration at the boundary nodes, a force of a magnitude equal to the acceleration times 10 was applied at the boundary node having a mass of 10 .

ANALYSIS OF THE VERTICAL LAUNCH SYSTEM

The MK41 Vertical Launch System (VLS) as shown in Figure 9 is an important addition to the United States Navy weapons arsenal. The MK41 system provides offensive and defensive capabilities in a single launcher and was designed as an alternative to single and dual-rail launching systems. The weapon system meets the Navy's needs for reliability, increased firepower, flexibility and reduced manning at manageable costs.

DTNSRDC/UERD was tasked by NAVSEA to participate in the predicting the shock response of the VLS in the recently constructed USS MOBILE BAY (CG-53) during full scale ship shock trials scheduled for the later part of May 1987. The specific objective of the UERD task was to predict the transient response between the VLS foundation and the USS MOBILE BAY ship structure. To accomplish this goal, NASTRAN/COSMIC finite element models were prepared for sections of the ship structure at the forward and aft launcher locations. A reduced mathematical representation (stiffness and mass matrices) of the VLS generated by the prime contractor, Martin Marietta, using NASTRAN/MSC on an IBM 370 computer was substructured into the ship structure models. The combined model was accelerated at the hull with a prescribed acceleration to simulate the expected motion of the ship during a full scale shock test in the vertical and athwartship directions in exactly the same technique described earlier for the MK-45 gun module. The results of these analyses were provided to Martin Marietta for use in detailed stress calculations through the time domain.

Figure 10 and Figure 11 illustrate the completed finite element models for the forward and aft launcher locations, respectively. In developing these models, substructuring capabilities of NASTRAN/COSMIC were extensively utilized to expedite model generation and to aid in combining the mathematical models of the VLS to the ship structure model. Figure 12 illustrates the use of the substructuring commands to generate the completed model of the forward launcher location. First a finite element model of one half of the ship structure as illustrated in

Figure 12a was created as a basic structure in a Phase One run. The centerline bulkhead structure illustrated in Figure 12b was also created as a basic structure. In addition, the mathematical representation of the VLS structure as illustrated in Figure 12c was used to define a basic structure via use of the INPUTT2 DMAP module. Finally, a Phase Two run was completed which created a symmetrical image of the basic structure in Figure 12a (illustrated in Figure 12d) and combined all the basic structure at interfacing grid points to form the complete ship structure. An additional Phase Two transient (Rigid Format 9) run was performed on the complete structure to obtain the motion at the foundation interface between the VLS and the ship structure. The results of this analysis was recovered via a Phase Three run and provided to Martin Marietta for the analysis of their superelement representation of the VLS through the time domain.

As previously mentioned, the USS MOBILE BAY will be shock tested in May 1987. The results of this analysis will be used to make comparisons with the experimental data obtained. The VLS will be heavily monitored during the test; hence, there will be an excellent data base to compare experimental and predicted results.

ANALYSIS OF MAST STRUCTURES ON USS KAUFMANN (FFG-59)

The dynamic response of mast structures under shock loading is of great concern to the ship shock community. Although the structural model of a mast type structure is rather simple, the complexity in the analysis comes from the assumed boundary conditions and the loading in terms of motion histories at these boundaries. DTNSRDC/UERD has been tasked by NAVSEA in support of the future shock trials of the USS KAUFMANN to develop a methodology to estimate the dynamic response of the masts and equipment supported by the masts.

The USS KAUFMANN supports two primary masts: Foremast/SPS-49 Support Tower and the Main Mast. The primary function of the foremast is to carry the SPS-49 Air Search Radar. This radar is an important element in the ship's C3I (Command, Control, Communications and Intelligence) capabilities. The main mast supports the great majority of the remainder of the ship's C3I equipment. This equipment aids the ship in communications, navigation and readiness for combat.

Figure 13 and Figure 14 illustrate the finite element models of the main mast and the foremast, respectively. The structural tubing and platform stiffeners were modeled using CBAR elements. Platforms on both masts were modeled using CQUAD2 and CTRIA2 plate elements. Equipment was modeled as concentrated masses via the CONM2 bulk data card.

As previously mentioned the complexity of the analysis of mast structures lies in the evaluation of the kinematic description of the boundary conditions. At the writing of this paper, studies are being conducted to develop a technique to determine the most valid set of boundary conditions to employ. The use of the "spar buoy"

model and the athwartship model discussed in preceding sections appears promising. Studies are being made to determine a mathematical model which accounts for the attenuation of the keel response (which the "spar buoy" model approximates) through the ship structure to the base of the mast structure at the weather deck level.

ANALYSIS OF SWATH STRUCTURE

The Small Waterplane Area Twin-Hulled (SWATH) ship is a unique United States Navy hull form. Figure 15 presents a cross sectional view of a SWATH ship finite element model. This half bay, half cross section finite element model was generated by the Ship Structures Division of DTNSRDC. The model was designed to analyze stresses generated in the haunched region by a psuedo-static wave loading on the strut. DTNSRDC/UERD was tasked to analyze the SWATH hull form to a shock loading from an underwater explosion.

The finite element model, provided by the Ship Structures Division, consists of membrane, plate, rod, and bar elements. The model employs 1500+ elements and 10000+ degrees of freedom. To conduct a dynamic analysis, several modifications were made to the model. The primary change involved increasing the mass of the model to equal the displaced mass of a comparable section of the ship under construction. The Nodal Weight Generator of NASTRAN/COSMIC reduced the effort of this modification.

A force-time history impulsive type loading was applied at the strut end cap to simulate the underwater shock loading. This type of loading was simple to calculate and to apply to the structure. An impulsive type loading could be applied to this structure because of the area of concern is the haunched region. Excessive stresses in the strut due to localization of the loading were ignored.

The shock loading from an underwater explosion to the SWATH hull form loads both struts and submerged hulls. The shock loading is not symmetrical (Figure 16). The near hull loading differs from the far hull loading in magnitude, direction, and phasing. To account for the unsymmetrical loading it was necessary to utilize a full cross section model of the SWATH. Due to the detail of the model and time requirements, substructuring was chosen to create an equivalent structure and combine the two substructures into one composite structure. Substructuring allowed for varying the magnitude and the direction of loadings to each substructure. Utilizing the DELAYS card, the phasing delay of the shock loading was easily implemented.

CONCLUDING REMARKS

This paper has presented the analyses using NASTRAN/COSMIC of several different types of naval structures subjected to a non-contact underwater explosive loading that the Underwater Explosions Research Division has conducted. Predicting the response of ships to withstand underwater shock loads is as much (if not

more) an art as it is a science. Hence the development of reliable analytical techniques to evaluate the response of ships to this type of shock loading provides a very fertile area for research. Using experimental and analytical methods, DTNSRDC/UERD is committed to assisting the Naval community in achieving this goal. The NASTRAN/COSMIC is an important tool in this task.

REFERENCES

1. Polmar, Norman, The Ships and Aircraft of the U. S. Fleet, Naval Institute Press, Annaplois, Md, Copyright, 1981.

2. Fallon, Dennis J.,"The Dynamic Response of Naval Structures to the Application of a Loading Function to Predict Underwater Explosions," Old Dominion University Research Report, March, 1985.

3. Mathewson, Alice W., "Calculation of the Normal Vertical Flexural Modes of Vibration by the Digital Process," TMB Report 706, February, 1950.

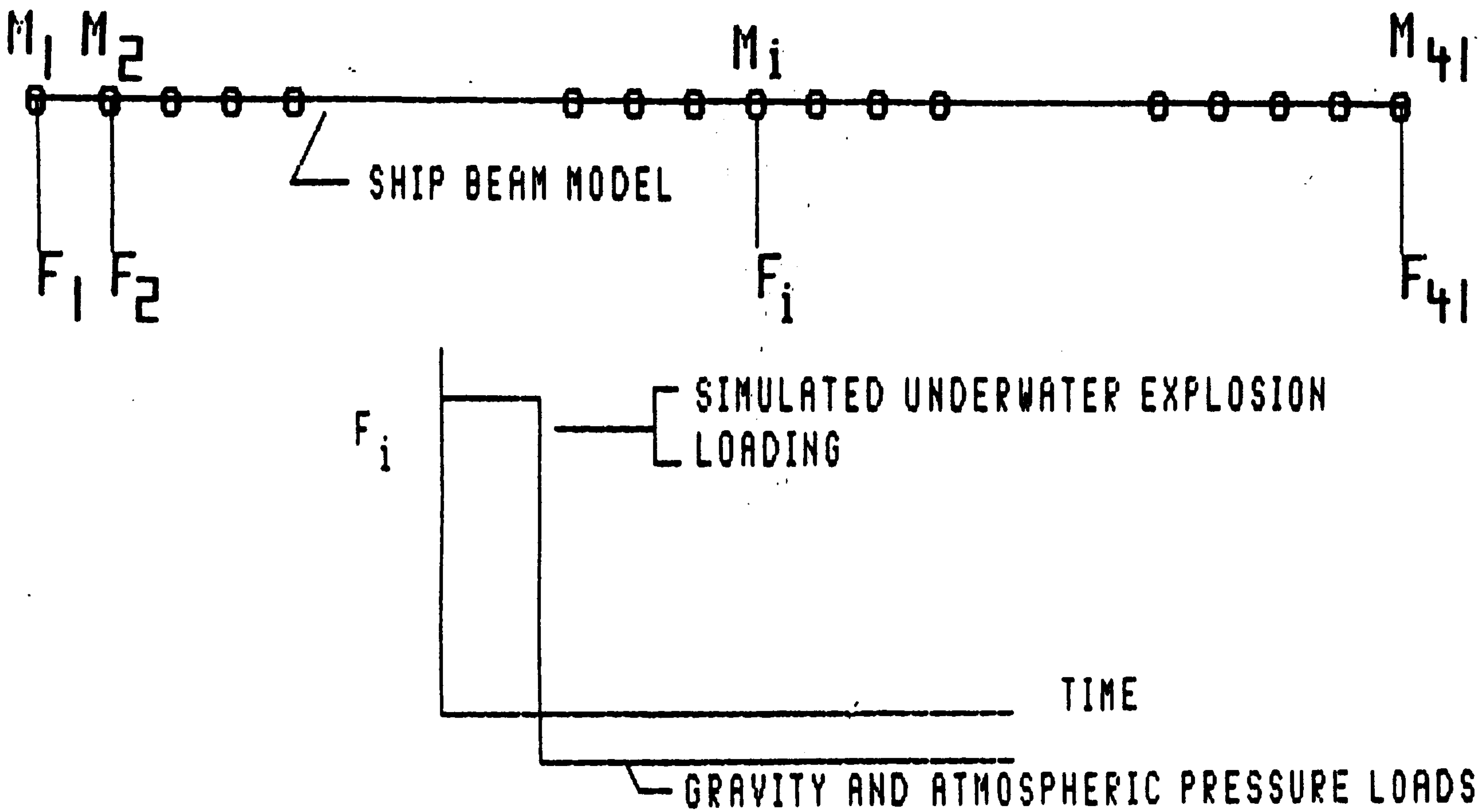

Figure 1: Ship beam model and loading function

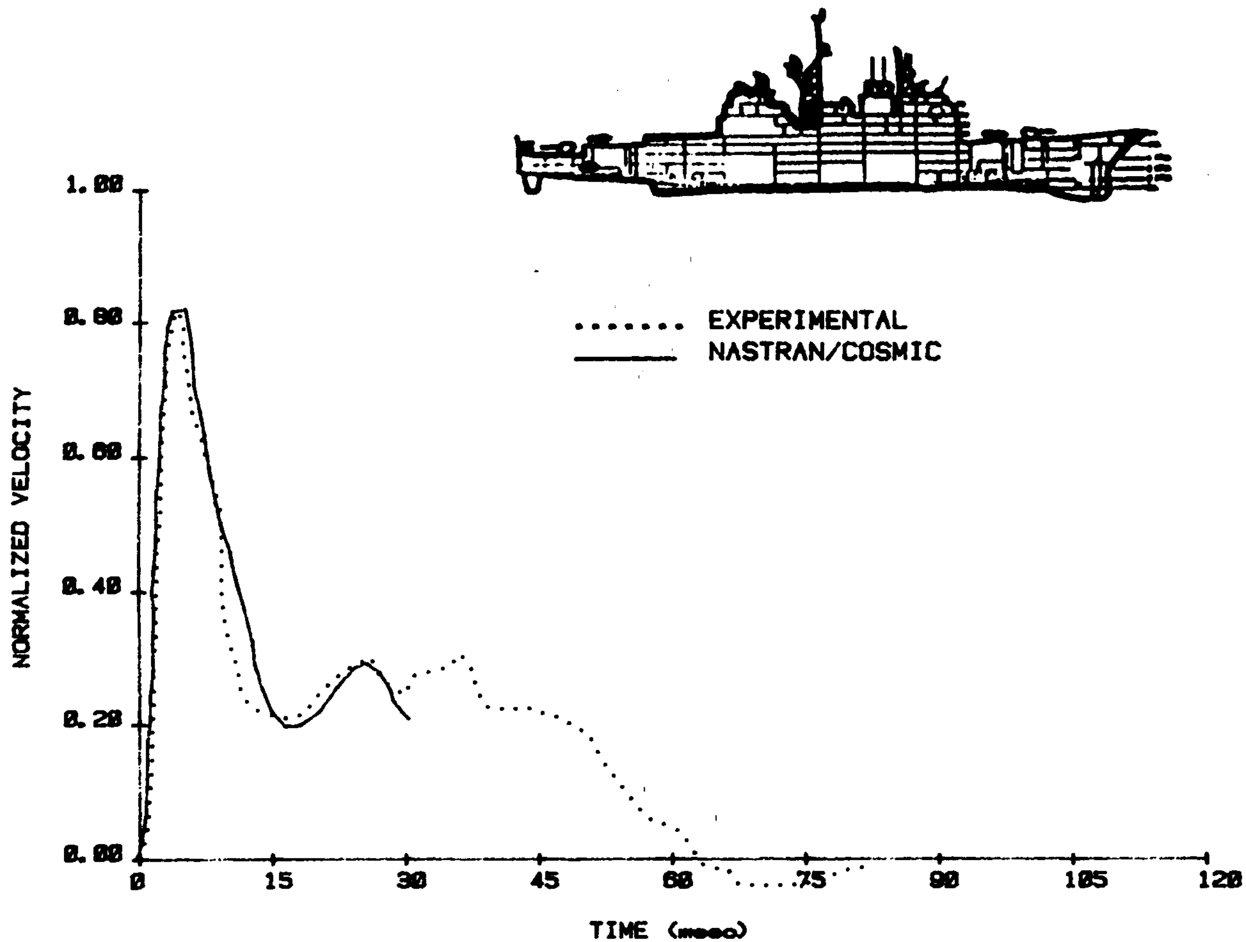

Figure 2: Velocity at the stern of USS YORKTOWN

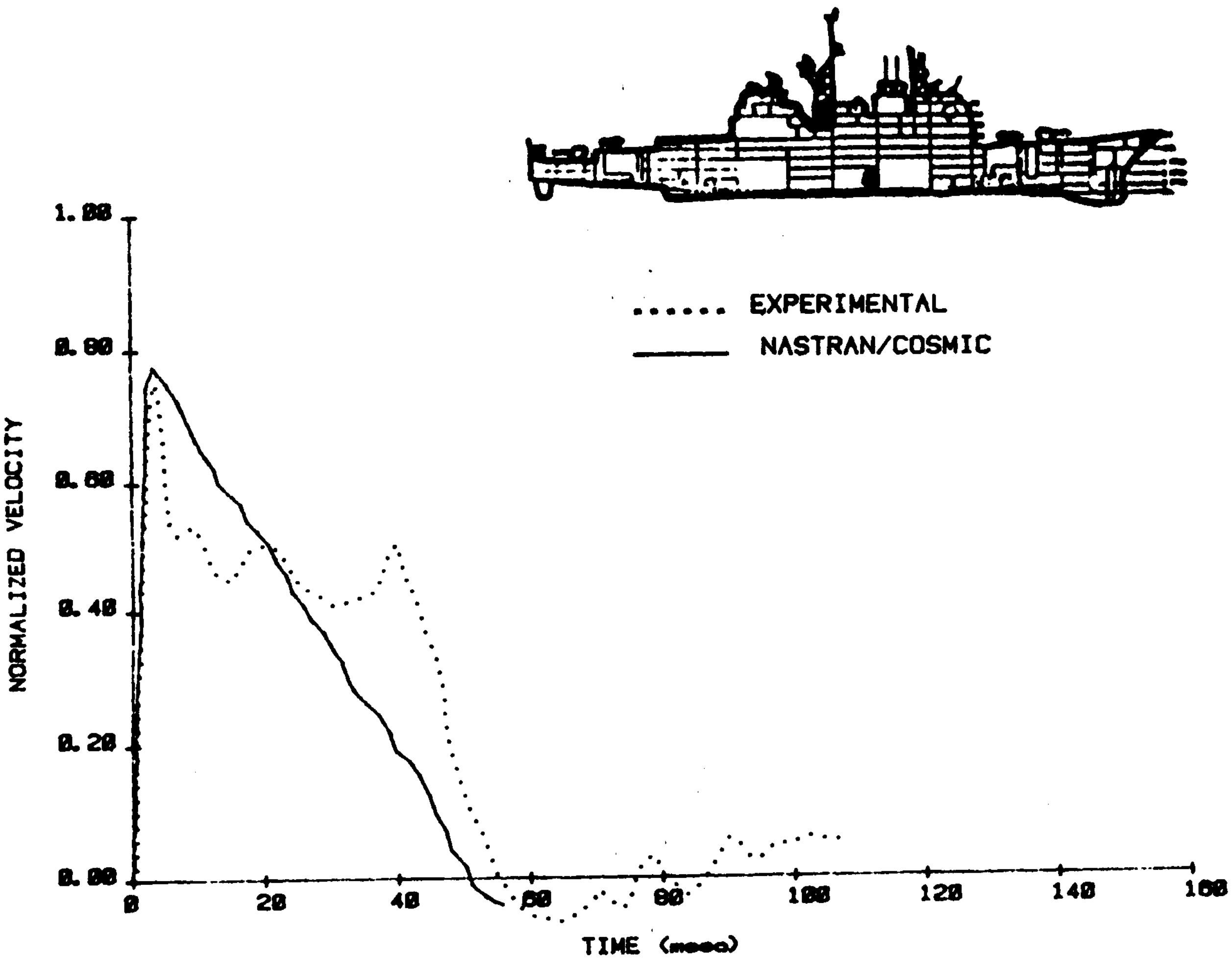

Figure 3: Velocity at amidships of USS YORKTOWN

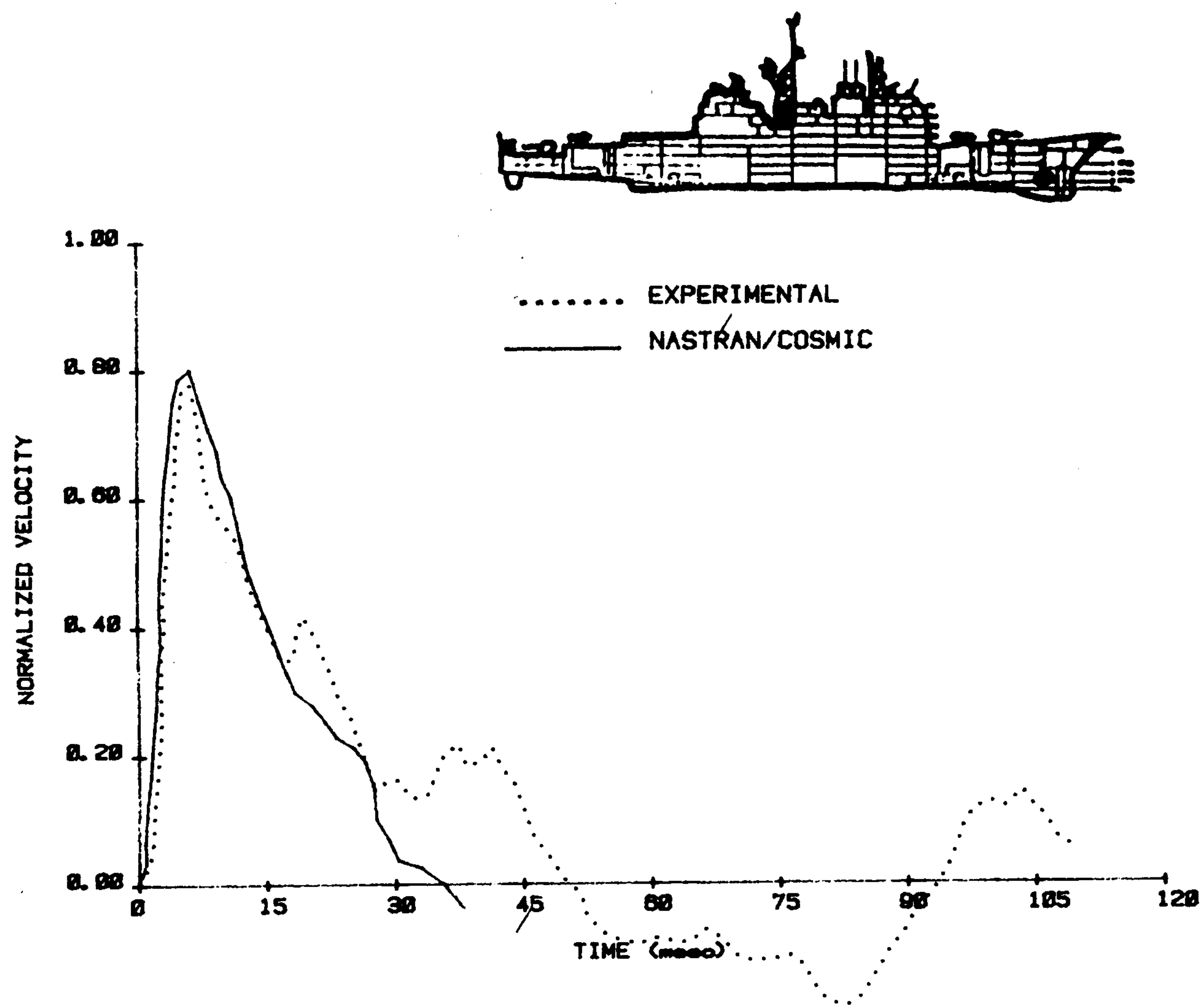

Figure 4: Velocity at bow of USS YORKTOWN

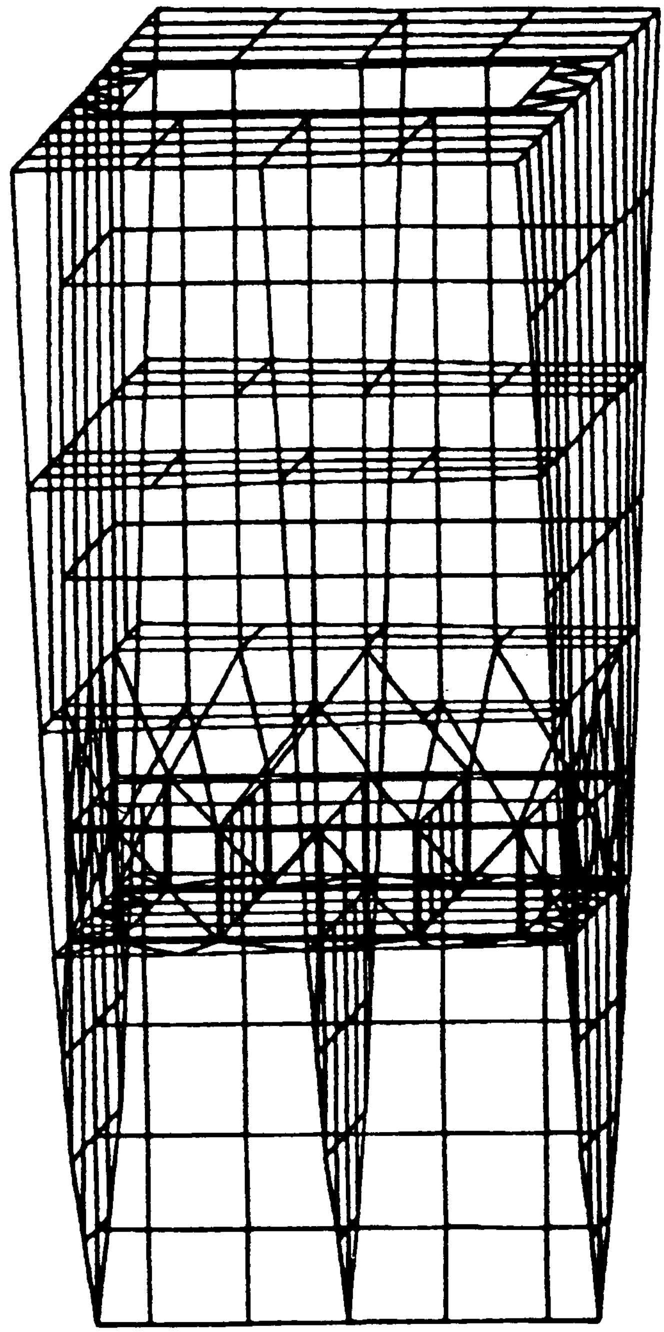

Figure 5: Finite element model DDG - 51 gun location

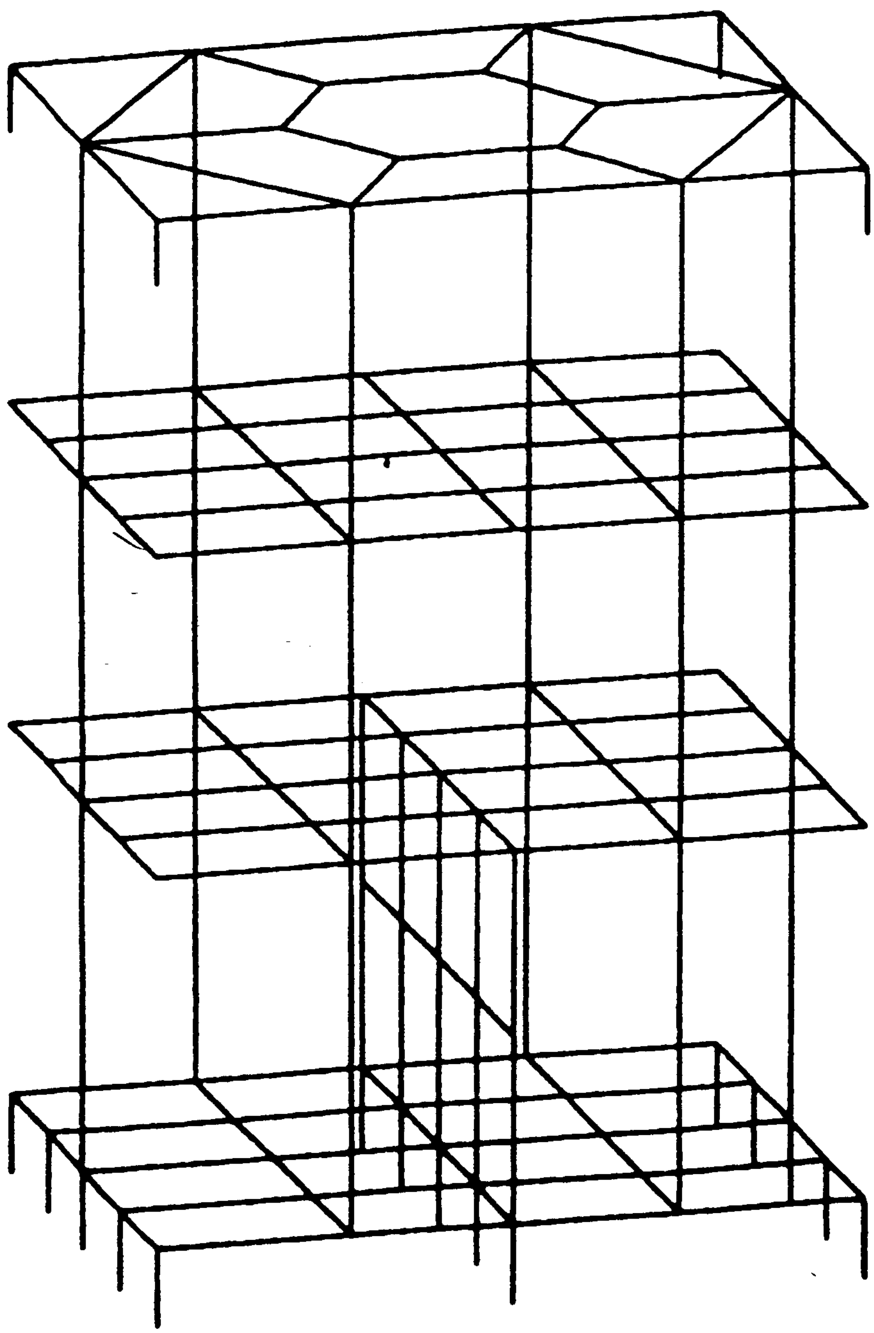

Figure 6: Finite element model MK45 gun module

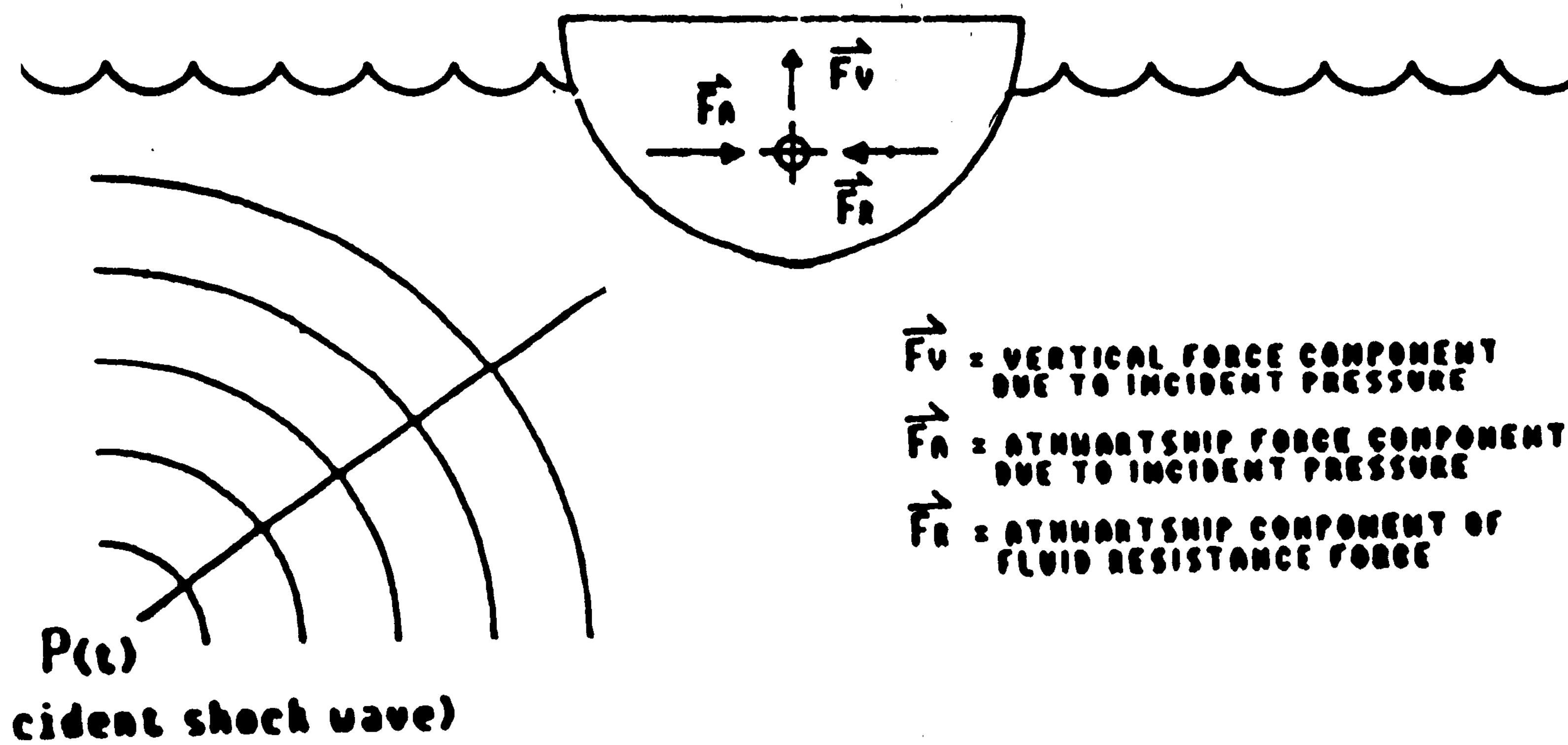

Figure 7: Athwartship mathematical model

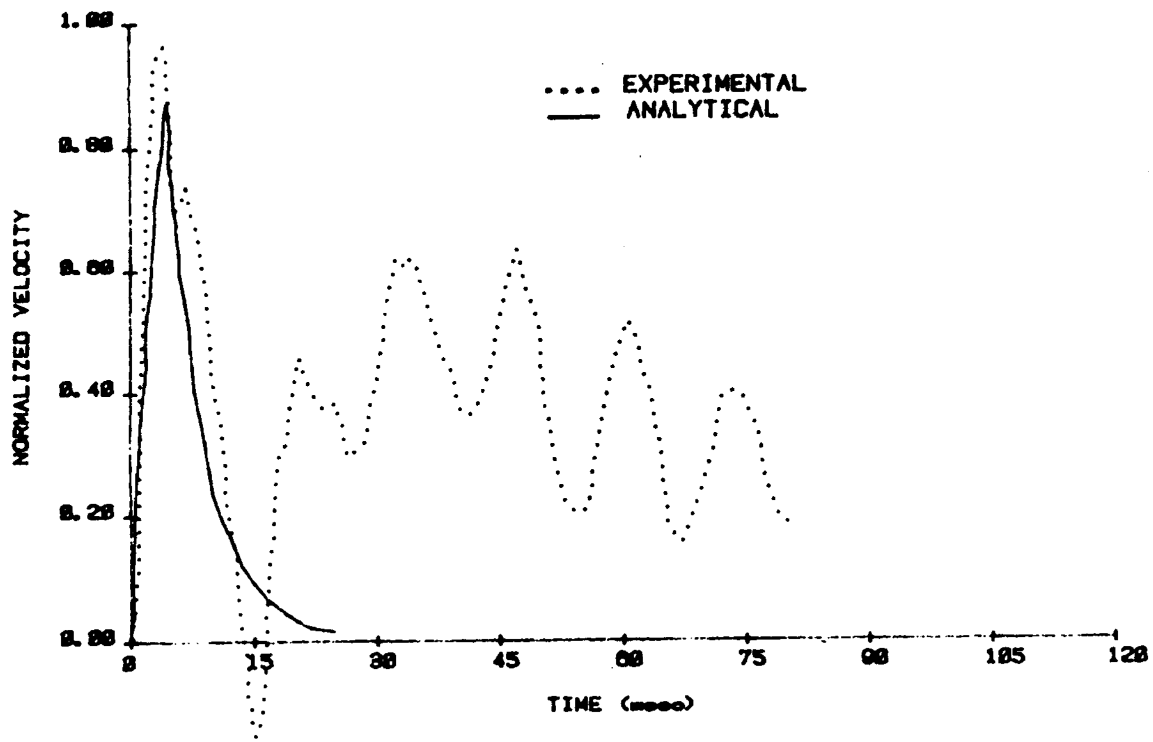

Figure 8: Comparison experimental and analytical athwartship motion USS YORKTOWN

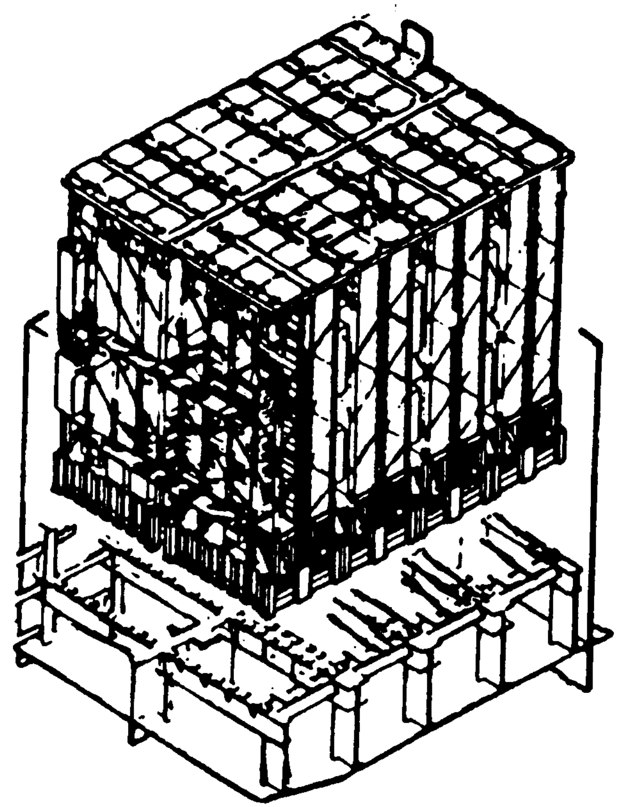

Figure 9: Vertical Launch Missile System

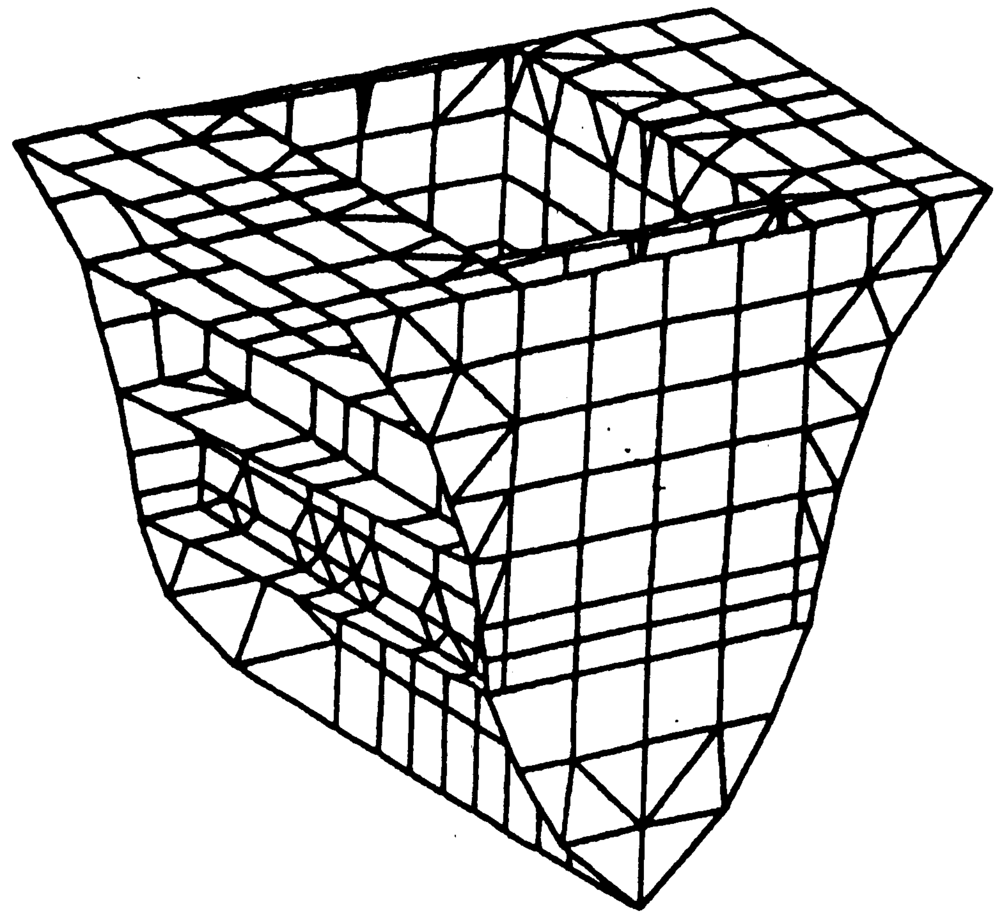

Figure 10: Finite element model forward launcher

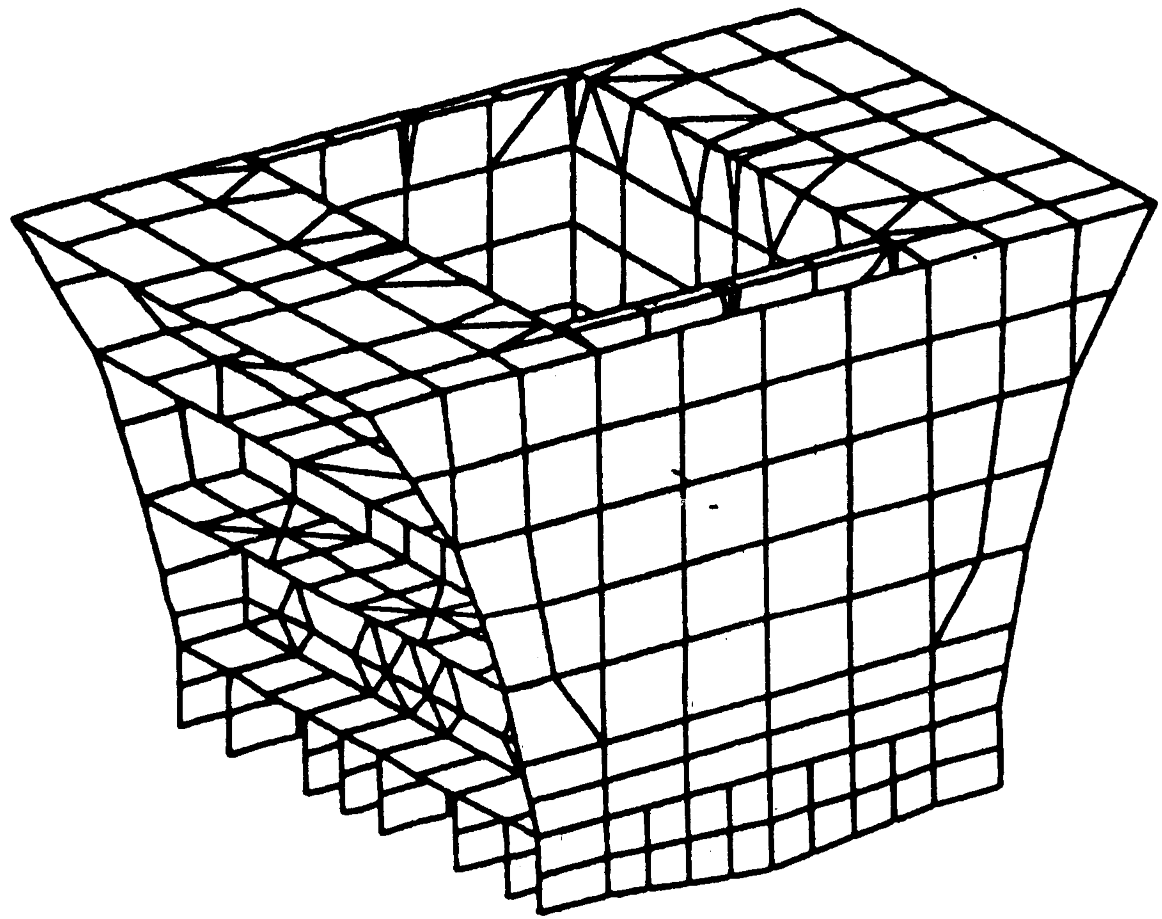

Figure 11: Finite element model aft launcher

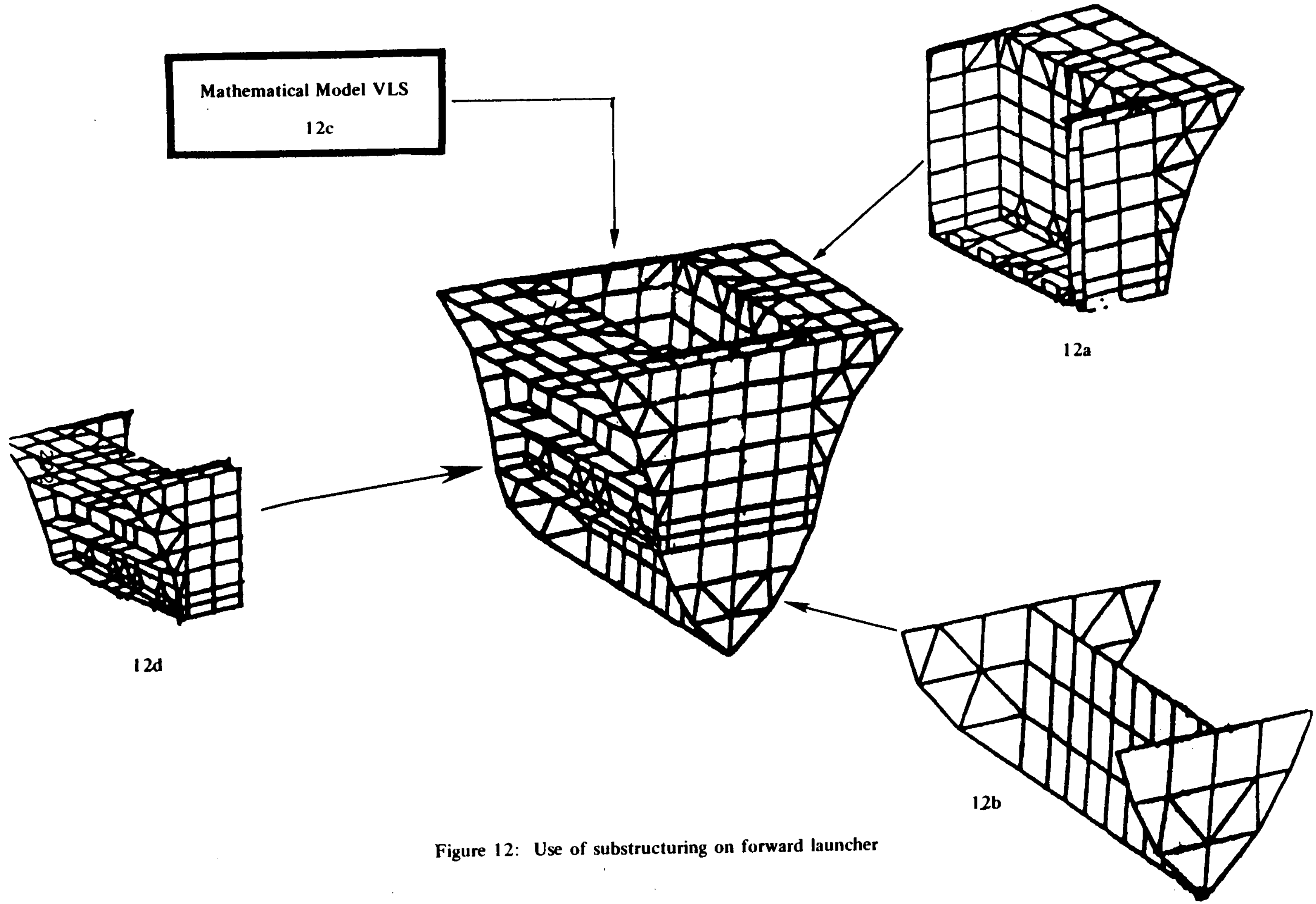

Figure 12: Use of substructuring on forward launcher

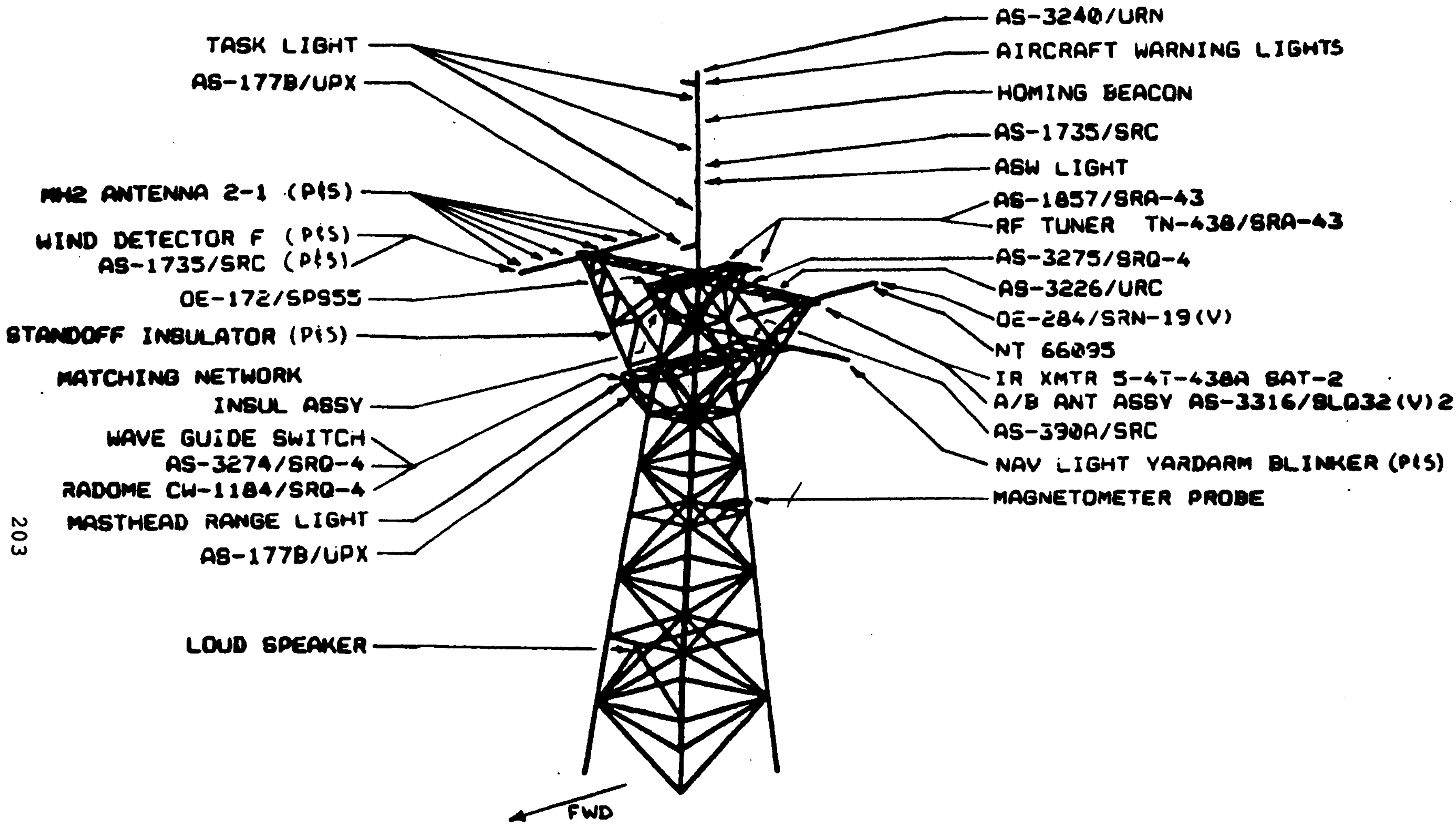

Figure 13: Finite element model of main mast

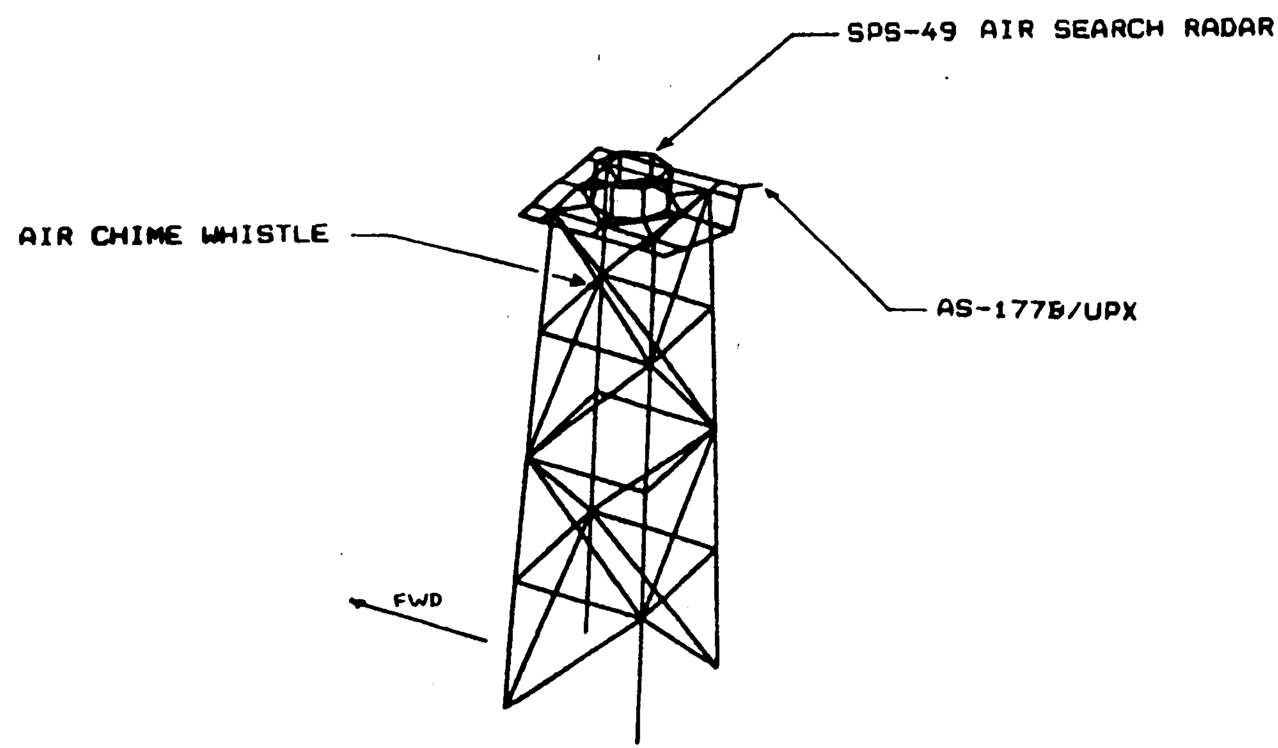

Figure 14: Finite element model of foremast

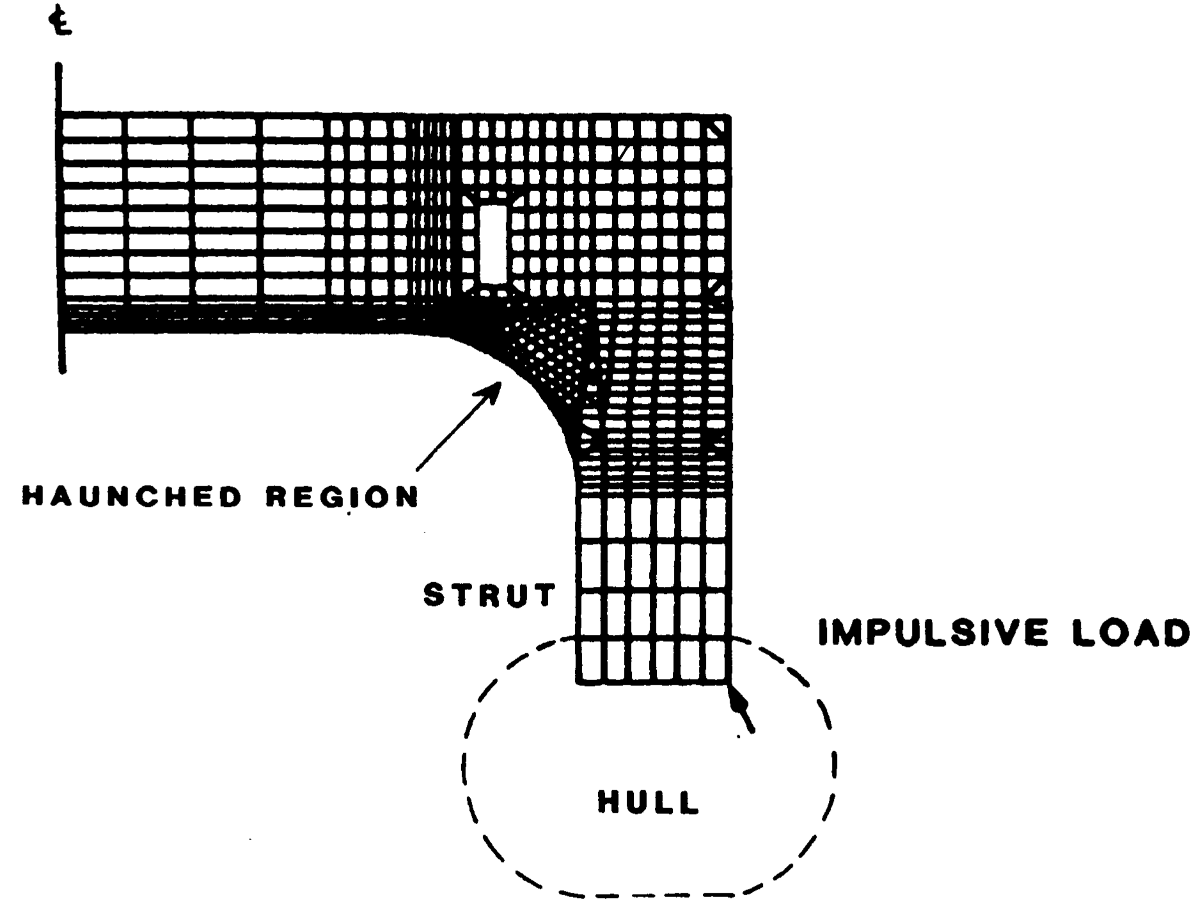

Figure 15: Finite element model of half cross section SWATH structure

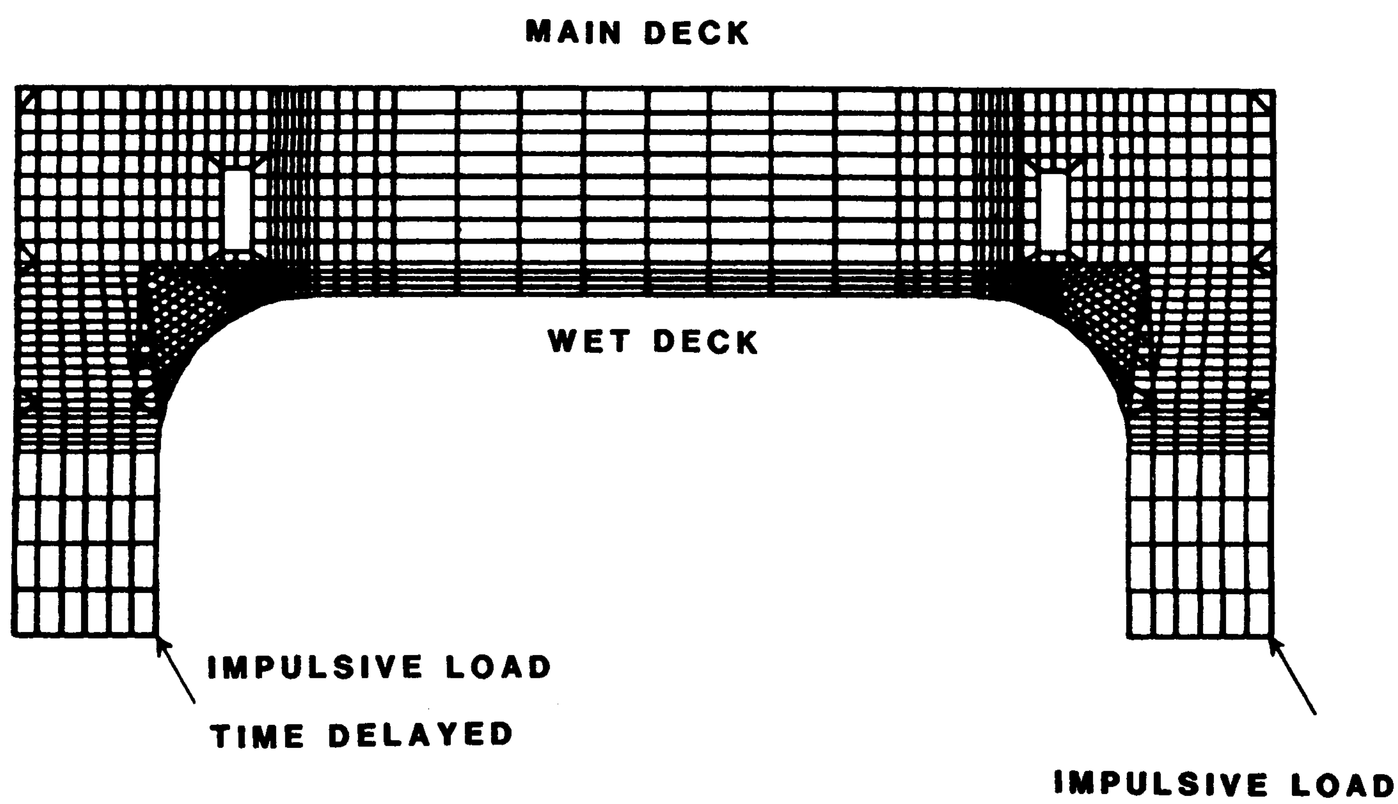

Figure 16: Finite element model of full cross section SWATH structure